PUBLIC HEALTH REPORTS

VOL. 34 MAY 23, 1919 No. 21

FISHES IN RELATION TO MOSQUITO CONTROL IN PONDS.

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I. Introduction.

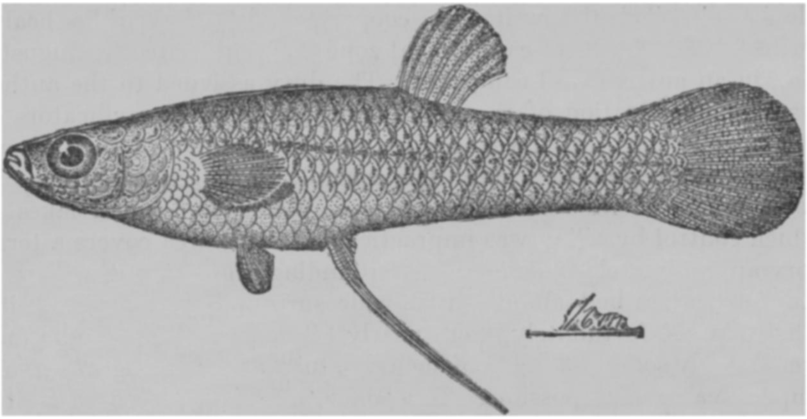
The United States Commissioner of Fisheries, in response to a request from the United States Public Health Service for an ichthyologist, detailed the writer to cooperate with the public health authorities of the extra-cantonment zone of Camp Hancock, Augusta, Ga., in an antimalarial campaign. The duty assigned to the author was an investigation of the effectiveness of fishes as eradicators of the aquatic stages of the mosquito, and the conduct of such operations as would promise secure "fish control" in the extra-cantonment zone, where there were many swamps, ponds, and small lakes in which control by oiling was impracticable. This area covers a territory approximately a mile wide surrounding the camp, the city of Augusta, and a belt about a mile wide surrounding the city limits. The swamps, fortunately, were nearly all drainable, but the ponds were mostly so situated and of such a nature that draining was either impracticable or impossible. The ponds, however, presented a situation which offered excellent opportunites for testing the practical value of fishes as eradicators of mosquito larvæ and pupæ. Experiments were at once started and observations were continued from March, 1918, to November 8, 1918. Much credit for the success of the work is due the local authorities of the United States Public Health Service for their excellent cooperation in furnishing labor, transportation, and other facilities for conducting the investigation.

Quite a number of species of fishes have been mentioned by writers in connection with the mosquito problem. The usefulness of some of these in aquaria and small pools, at least, is well known, but accurate information as to their effectiveness in larger bodies of water, and especially in places where the immature mosquito finds protection among plants or débris, is largely wanting. The summer's investigation was almost wholly devoted to the determination of the practical value in antimalarial work of the top minnow, *Gambusia affinis* (Baird and Girard).

The experiments were conducted in a large series of ponds which afforded many different conditions. It is the writer's intention to relate how the investigation was conducted and to mention results and conclusions. It is hoped that the value of the top minnow may become better understood thereby and that the observations reported will be of help to those who in the future may wish to employ this useful little fish in antimalarial work.

II. General Topography of Augusta and Surrounding Territory.

The city of Augusta is situated on the Savannah River, in a low and rather flat valley, and because of the recurrence of floods and the consequent danger to life and property, a levee was constructed between the river and the adjacent territory. However, there is a considerable elevation westward or toward the "Hill" section of the



Gambusia affinis (male).

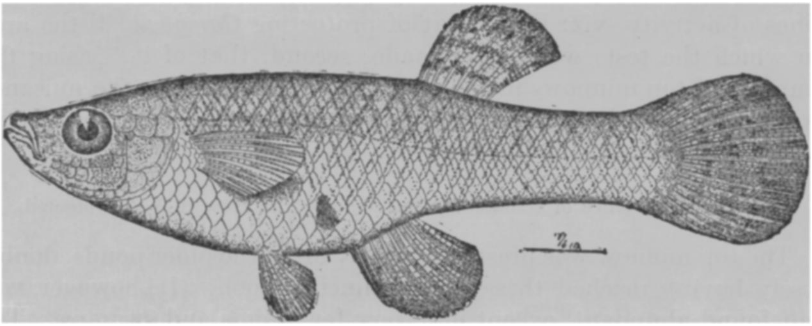
city, beyond which lies Camp Hancock. The one-mile belt surrounding the city extends across the Savannah River and includes a section of South Carolina. There were many swamps in this rather flat territory, but fortunately most of these were drainable and have been eliminated by the United States Public Health Service in cooperation with the authorities of Richmond County and the city of Augusta. In addition to the swamps there are many ponds. Nearly all of these are artificial and they vary in size and depth. Drainage, in most instances, is impracticable, if indeed not impossible. The majority of these ponds were made in the manufacture of brick, an industry which was started in Augusta in about 1808. The clay pits made by these manufacturing concerns, because of the flat nature of the country, soon become filled with water. Sometimes after hard rains the water is pumped out and digging is resumed in the old pits, but frequently the digging machines are moved. Thus new ponds are being formed constantly. There are more than one hundred of

these clay pits in the territory under protection, and in addition there are a number of ponds or lakes which were made for the purpose of furnishing a water supply, or for water power.

These ponds present a variety of conditions. Some of them are very old and have become partly filled with sediment; the shores are often gently sloping and much aquatic vegetation is present. Such ponds usually furnish an ideal environment for the support of mosquito larvæ. The newer ponds generally have steep shores; there is not much vegetation, but considerable wave action, and as a rule these ponds are not well suited to prolific mosquito breeding.

III. Gambusia Affinis and the General Plan Pursued in Testing Its Value in Anti-Mosquito Work.

Gambusia was selected for the present tests because, first, it seeks its food at the surface, which appears to make it especially suitable for antimosquito work; second, it lives and thrives under a large



Gambusia affinis (female).

variety of conditions and especially in water suitable for the support of mosquito larvæ; third, it proved to be quite common in the extra-cantonment zone and adjacent territory; fourth, it is very prolific; and fifth, its usefulness in destroying mosquito larvæ in aquaria and fountains was already well known.

This fish does not lay eggs, but gives birth to well developed and very active young. It, therefore, requires no special environment, as most other fishes do, for depositing and hatching the eggs. Young of the season were noticed for the first time on April 24, and during the latter half of October a gravid female still occasionally appeared among collections. The author,[1] working with *Gambusia* at Beaufort, N. C., found that it breeds throughout the summer and that a new brood is produced at intervals of about one month or six weeks. It was observed that a single female gave birth to six broods of young during a single season. The number of young produced at

[1] Hildebrand, Samuel F., Report U. S. Commissioner of Fisheries, Appendix VI, 1917, p. 6.

one time appears to bear a direct relation to the size of the female, a large female producing many more young than a small one. The largest brood observed by the writer numbered 63, but Smith,[1] working with fish from the Potomac River, found 100 in a single brood. The young are approximately one-half inch in total length when born; they are very active and are apparently much better adapted to begin the struggle for an existence than most fish hatched from eggs. They, in fact, are ready to begin the work of destroying mosquito larvæ at once, for the writer has seen them attacking and eating small and even medium-sized mosquito larvæ in aquaria before they were a day old. *Gambusia* gains growth rapidly and the earliest broods of the season, born in April and May, become sexually mature and produce young when four to five months old. The later broods of course do not produce young until the following season.

The general plan pursued in testing the practical value of the top minnow in antimalaria work may be divided into three principal lines of activity, viz: First, that of protecting *Gambusia* in the area in which the tests were to be made; second, that of increasing the number of top minnows in the ponds in which the mosquito nuisance was to be abated by means other than protection; and, third, that of making careful field observations.

IV. The Abundance of Gambusia, Its Enemies, and How It Was Protected.

The top minnow was present in nearly all of the older ponds, doubtlessly having reached these during times of flood. It, however, was not found abundant, except in a very few ponds and swamps. The common local practice of using *Gambusia* for bait for larger fish without doubt resulted in keeping the top minnow from becoming more abundant. Then there were certain ponds with insufficient shallow water to provide protection for the minnows from larger fish, and in at least one instance a lake had become greatly overstocked with predacious fishes, so that there was a great dearth of food. This lake is situated in Allen Park, within the city of Augusta. It had been artificially stocked with large-mouthed black bass, locally known as "trout," in addition to several species which probably reached it during floods. Bass of 3 inches and upward in length were almost constantly present in very shallow water, preying on the top minnows. Sunfishes were also present in the shallow water, but it was not observed that they actually fed on the minnows. In August it was quite evident that fewer *Gambusia* were present in this lake than there were in April, notwithstanding the fact that approximately 18,000 minnows had been introduced from other

[1] Smith, H. M., Science, n. s., vol. xxxvi, 1912, p. 224.

sources during the intervening months. Other ponds apparently well stocked with sunfishes and bass, and which certainly did not offer better protection for the minnow than the lake in Allen Park, were stocked with *Gambusia*, but in none of these did such disastrous results ensue. In Allen Park all fishing was prohibited, while in the other ponds there was a limited amount of hook and line fishing. The entire prohibition of fishing in Allen Park doubtlessly accounts for the great abundance of predacious fishes, and the shortage of food made it necessary for the fish to venture into shallower water than they ordinarily do in search of food. Later when an effort was made to give *Gambusia* a chance of survival in Allen Park, it was learned that the shortage of food was so great that cannibalism had undoubtedly prevailed.

The following experiment shows that the common local species of sunfishes are not serious enemies of *Gambusia*. It, therefore, is quite certain that the bass was the chief enemy of the minnow in Allen Park. An old pond, measuring about 75 by 50 feet, with an average depth of approximately 5 feet, was stocked during the first week of April with about 3, 000 sunfishes. Probably about 90 per cent of the fish were bream, *Lepomis incisor* (Cuvier and Valenciennes), and the others were warmouth and a few of other species. The pond was already well stocked with *Gambusia*, and it doubtlessly possessed conditions suitable for the propagation of the top minnow, but probably not for that of sunfishes. However, there were present before stocking a few sunfishes. The bottom of the pond was very muddy, the shore edges were almost free of vegetation; there was little algæ and the water was quite foul. Nearly all of the sunfishes lived, so far as known, and the top minnow made a notable increase during the summer. It undoubtedly is true that *Gambusia* is not as abundant in this pond with the large number of sunfishes present as it otherwise would have been, but the experiment certainly shows that the bream is not very destructive to the top minnow.

Gambusia in a few instances needed protection from natural enemies, but much more generally from man. The top minnow had become quite a favorite bait for larger fish, and wherever this fish was fairly common, fishermen and bait collectors were frequently seen catching it with small seines and dipnets. This practice quite certainly did more than any other one thing toward preventing *Gambusia* from becoming more abundant. Consequently, it was thought advisable to publish a notice in the local newspapers, explaining that this fish was useful in destroying the wiggle-tail and asking fishermen to kindly discontinue using it for bait. In addition, a placard was posted at each pond, stating that the small fish were protected as a health measure and that they were not to be used for bait. The

response to these requests was most cordial, as not an offender was seen.

Several ponds with steep shores provided very little shallow water and the top minnow did not thrive. These ponds supported larger fish, including the large-mouthed black bass, and it is believed that they destroyed the minnows. The chief protection which *Gambusia* finds from the larger predacious fishes, appears to be shallow water. An effort, therefore, was made to provide this protection in the above-mentioned ponds by grading the shore at several points in each pond. The difficulty encountered in the pond in Allen Park has already been mentioned. This greatly overstocked lake was seined and a large number of predacious fishes were removed. It was then restocked with *Gambusia*, and after that, bass were not observed feeding on the top minnow. The provisions against natural enemies were made too late in the season to bear very evident results during the present investigation.

V. Means and Methods Employed in Stocking Ponds With Gambusia.

Minnows for stocking ponds were secured mainly from two sources; first, from swamps within the protected area which were being drained; and second, from waters outside of the extra-cantonment zone, from places where minnows did not appear to be needed. Large numbers of minnows were secured from these sources and placed in ponds where few or none were present.

One pond, about 100 by 30 feet, with an average depth of about 3 feet, was used as a "hatchery." This pond has a very muddy bottom and it supports much algæ and several attached plants. All fish were removed from this pond. Then a partition, composed partly of a dam and partly of wire netting, was built across the pond. About 3,000 adult female *Gambusia* were placed in the larger compartment. No record was kept of the number of males which were introduced, as this is relatively unimportant,[1] but there were probably not more than 10 to each 100 females. The purpose of dividing the pond into two compartments, using a one-fourth inch wire screen for a portion of the partition, was to give the young fish an opportunity to migrate to that section of the pond where they could not be followed by the adults. This was thought advantageous because of the cannibalistic habit of *Gambusia*, which the mother, in confinement at least, so impressively displays by eating her own young oftentimes nearly as rapidly as they are born. The one-fourth inch mesh, however, proved to be a little too large and some of the adults succeeded in getting through it. The reproduction in this hatchery, nevertheless, exceeded all expectations. This pond,

[1] Hildebrand, Samuel F., Report U. S. Commissioner of Fisheries, Appendix VI, 1917, p. 7.

being conveniently situated, furnished a ready supply of top minnows for aquaria, fountains, pools, and wells wherever they were found to be needed or as requests for them were received.

A very useful net for collecting top minnows is a small bobbinet seine. The one used by the writer was about 12 feet long and 3 feet deep. Such a net, if made of a good grade of netting, is light and durable, and it can be quickly and easily handled. A dipnet, also made of bobbinet, was used to some advantage in places where there was so much vegetation that a seine could not be operated.

VI. Observations and Experiments.

Field observations were made at all ponds in the protected zone at more or less definite intervals of one week each throughout the investigation. These were often extended beyond the protected area for the purpose of obtaining checks on the effectiveness of the work within the zone.

As early as March 29 a certain pond was found to be fairly alive with mosquito larvæ and pupæ. Further investigation proved that no fish were present. Top minnows were then placed in the pond for the purpose of observing whether or not the fish would destroy the large numbers of immature mosquitoes. The fish, however, all died in less than 45 minutes. Since the pond was near that portion of the Georgia Chemical Works where sulphuric acid is manufactured, the presence of a chemical fatal to fish life was at once suspected. A litmus-paper test gave a strongly acid reaction. While the first purpose of the experiment failed, it, nevertheless, was learned that mosquitoes can breed in water so strongly acid that *Gambusia* is killed almost instantly thereby. There, however, was another pond very near the acid pond and in appearance very similar to it. This one was well supplied with top minnows in addition to a few food fishes, and it was entirely free of mosquito larvæ. As it did not seem reasonable that mosquitoes would select the acid pond in preference to the unpolluted one for breeding purposes, the only apparent logical conclusion was that the absence of mosquito larvæ in the latter was due to the presence of natural enemies or fish.

Another situation very similar to the one discussed in the preceding paragraph was not far away, for there were nearly end to end an acid swamp and the pond previously referred to as the hatchery. *Anopheles* bred in the acid swamp throughout the season, except as interrupted from time to time by the application of oil. The hatchery pond, which was evidently well suited for the support of *Anopheles* larvæ, was, nevertheless, free from them, except when the vegetation became dense and provided protection.

On April 1, mosquito larvæ of the *Culex* type were found in a ditch, in several pools, and in a large pond. These waters were all free of débris and vegetation. The pond had steep shores and it was very clean. It was one of the newer brickyard ponds and no fish were present. All of these places, being close together, were stocked with *Gambusia* at the same time. Only 6 fish were placed in each of the pools, which were about 10 to 12 feet long, about 2 feet wide, and very shallow. Each pool supported thousands of mosquito larvæ, but in about two weeks they were made entirely free of wrigglers by the fish and remained so until they became dry later in the season. The presence of comparatively few skins showed that not many of the larvæ reached the adult stage. The ditch referred to was approximately 30 feet long and 1 foot wide. Mosquito larvæ were especially abundant in it. About 200 top minnows were placed there and in two weeks it was completely free of wrigglers. Mosquito larvæ were seen only along the shore of the big pond. It was at first stocked with about 1,500 *Gambusia*, but later several thousand more were added. The larvæ in this pond, too, disappeared in about two weeks from the time the first fish were introduced and none were again seen until September. By that time the shores had become overgrown with vegetation which furnished protection for *Anopheles* larvæ against fish. This vegetation was cut and the shores were raked. A large school of top minnows followed the workmen, destroying the immature mosquito and other insect larvæ as quickly as their hiding places were destroyed.

It was possible in several instances to connect ditches and swamps which were thickly infested with mosquito larvæ with ponds that were well supplied with top minnows. Wherever this was done, large numbers of fish entered these waters and destroyed the mosquito larvæ in a surprisingly short time.

For the purpose of comparison and as further evidence of the value of *Gambusia* in controlling mosquito breeding two other small ponds are worthy of mention. These ponds are situated at the intersection of the tracks of the Georgia Central and the Belt Line railroads, and they are of about equal size. The top minnow had reached one of the ponds from an unknown source, and it was entirely free of mosquito larvæ. The other was without fish, and mosquitoes were breeding in it in abundance. The inference, in the absence of any evidence to the contrary, of course, is that the top minnows destroyed the mosquito larvæ in the first pond.

During the latter part of October two new brickyard ponds were found to be breeding large numbers of mosquito larvæ. The ponds had become supplied with some vegetation; the mosquito larvæ, however, were not confined to these hiding places, but were quite generally distributed over the ponds, and could be seen in perfectly

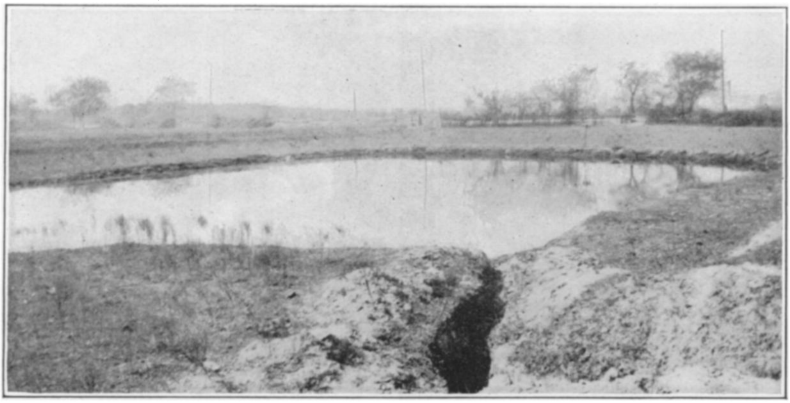


FIG. 1.—POND ABUNDANTLY STOCKED WITH SUNFISHES AND TOP MINNOWS.

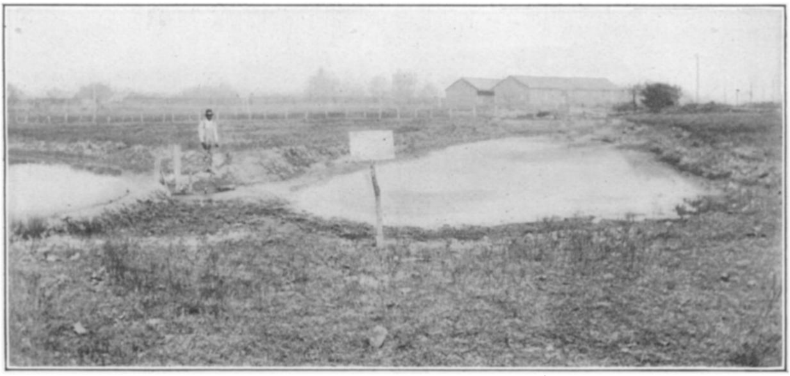


FIG. 2.—SECTION OF HATCHERY.

Notice reads: "Small fish in this pond are protected by the United States Public Health Service as a health measure, and must not be used for bait."

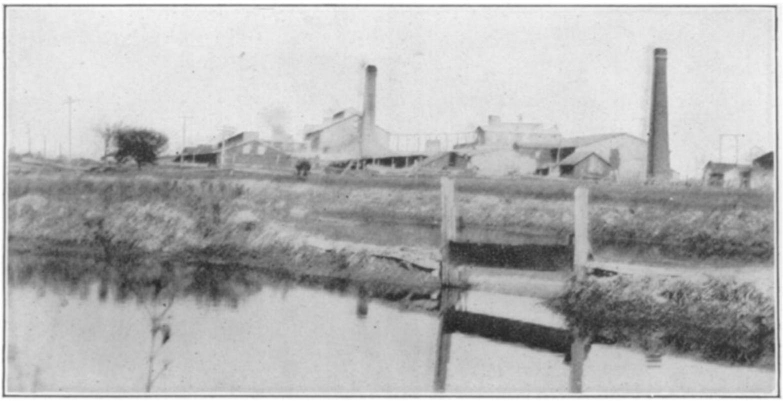


FIG. 3.—SECTION OF HATCHERY SHOWING PARTITION BETWEEN PONDS (A PORTION OF THE GEORGIA CHEMICAL WORKS IN BACKGROUND).

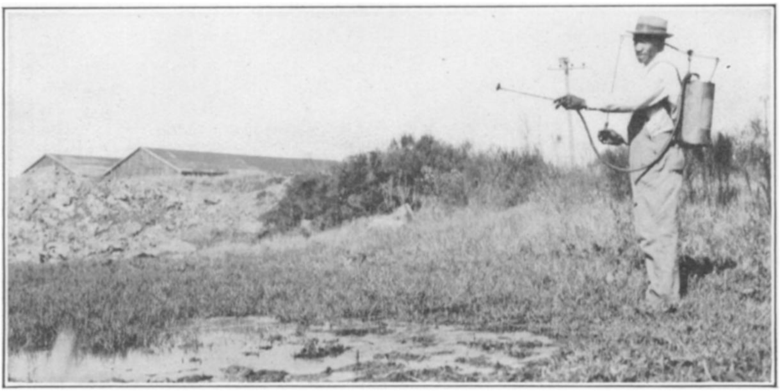


FIG. 4.—SPRAYING OIL ON AN ACID SWAMP IN WHICH FISH CAN NOT LIVE BUT WHICH SUPPORTS ANOPHELES LARVÆ.

FIG. 5.—SECTION OF CLEAN SHORE OF A POND WHERE MOSQUITO LARVÆ WERE ABUNDANT BEFORE INTRODUCING TOP MINNOWS.

FIG. 6.—SHOWING GROWTH OF AQUATIC GRASS IN CORNER OF POND. SUCH GRASS FURNISHES EXCELLENT PROTECTION FOR MOSQUITO LARVÆ.

FIG. 7.—AQUATIC GRASS GROWING ALONG THE SHALLOW EDGE OF A POND WHERE IT FORMS PROTECTION FOR MOSQUITO LARVÆ.

FIG. 8.—FLOATING PLANTS OF MYRIOPHYLLUM AND DÉBRIS WHICH PROVIDE PROTECTION FOR MOSQUITO LARVÆ.

FIG. 9.—TREATING POND WITH COPPER SULPHATE FOR KILLING ALGÆ. LABORER IS DRAGGING A SMALL BAG OF THE CHEMICAL THROUGH THE WATER BY MEANS OF A POLE.

FIG. 10.—SPRAYING OIL ON ALGAL PADS TO DESTROY THEIR USEFULNESS AS HIDING PLACES FOR THE IMMATURE MOSQUITO.

FIG. 11.—SECTION OF POND SHOWING PRESENCE OF WATER LILIES.

FIG. 12.—RUSHES GROWING IN END OF POND. THESE PLANTS RARELY PROVIDE PROTECTION FOR MOSQUITO LARVÆ.

FIG. 13.—TALL RUSHES AND GRASSES WHICH DO NOT PROVIDE PROTECTION FOR MOSQUITO LARVÆ.

FIG. 14.—POND SUPPORTING DENSE VEGETATION CONSISTING PRINCIPALLY OF SMART WEEDS WHICH DO NOT PROVIDE PROTECTION FOR MOSQUITO LARVÆ.

FIG. 15.—SECTION OF POND SHOWING ABUNDANT GROWTH OF TALL VEGETATION WHICH DOES NOT PROVIDE MUCH PROTECTION FOR MOSQUITO LARVÆ.

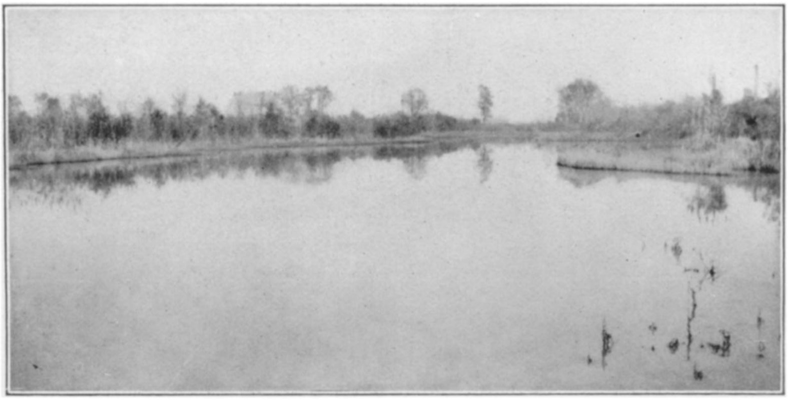


FIG. 16.—DISTANT VIEW OF POND. MUCH MARGINAL VEGETATION WHICH USUALLY FURNISHES SOME PROTECTION FOR MOSQUITO LARVÆ.

FIG. 17.—SHOWING MARGINAL VEGETATION REMOVED.

FIG. 18.—SPRAYING OIL ON ALGAL PADS.

In foreground is seen some of the aquatic grass, Hydrochloa caroliniensis, which provides excellent protection for mosquito larvæ.

clear water. *Anopheles* larvæ previously had been noticed only once away from all protection, and then, as now, in a pond not stocked with fish. On October 23 about 1,000 *Gambusia* were placed in one pond and the other was left as a control. On October 26 no pronounced reduction in the number of larvæ in the pond which had been stocked was noticeable. On October 29, however, a remarkable decrease was evident, only a few larvæ being left, and these were found in vegetation. At the end of this time the immature mosquitoes in the other pond (control) were as abundant as ever.

Many similar experiments and observations could be mentioned, but as the results for all were nearly identical it is not advantageous to do so. It then may be stated that wherever mosquitoes were breeding prolifically *Gambusia* was not present, but, if introduced, mosquito breeding was eliminated or at least greatly reduced. Wherever the complete elimination of mosquito larvæ did not result, if sufficient top minnows were present the immature mosquitoes were so protected by vegetation or débris that they could not be detected or reached by the fish.

All aquatic plants, however, do not furnish protection for mosquito larvæ and pupæ against fish, and some even may be repellent. The following-named plants appeared to provide good protection and caused considerable trouble during the investigation: *a*. The aquatic grass, *Hydrochloa caroliniensis; b*. "Coon-tail moss," a species of *Myriophyllum;* and *c*. Algæ. The aquatic grass grows in shallow water and along the shores. It has many slightly submerged leaves over which the horizontally floating or swimming *Anopheles* larvæ hover, out of sight and out of reach of fish. Wherever this plant occurs some *Anopheles* larvæ are almost sure to be present regardless of the abundance of *Gambusia*. It, therefore, is obvious that if this plant occurs in ponds in which mosquito control is desired, it must be removed. This may be done by cutting and raking, or if growing in soft mud it may be pulled up by the roots.

The plant locally known as "coon-tail moss" causes trouble omy when it becomes detached and rises to the surface. This plant was present in only a few ponds in which an endeavor was made to secure mosquito control, and it caused considerable trouble in only one. It is ordinarily attached to the bottom, but in this instance some of the plants became detached from time to time and came to the surface. There each plant collected more or less débris, algæ grew among its branches and thus formed a mass in which both types of mosquito larvæ found protection. This floating mass must be removed from time to time, and can be done best on a windy day when it drifts inshore.

Algæ often form mats which float at or near the surface. Mosquito larvæ, praticularly *Anopheles*, find protection from fish over and in

these mats. Copper sulphate was used in the proportion of 8 pounds to 1,000,000 gallons of water for killing the algæ, but this treatment must usually be repeated frequently. Toward the close of the season a light gas oil, used by the local office of the United States Public Health Service in antimalaria work, was sprayed on the algal pads wherever the use of the water did not preclude this practice. This oil, if used in moderate quantities, is not injurious to fish; it can be quickly and conveniently applied, and it is very effective, for the alga pads act like sponges, retaining the oil and making them uninhabitable for the mosquito.

Water lilies do not, as a rule, appear to furnish much protection while growing, but some of the plants die from time to time. The leaf then often partly sinks, forming a depression over the center while the edges remain at the surface. The cup thus formed holds enough water to support mosquito larvæ, and with respect to fish the larvæ contained therein are perfectly safe. When the dead leaves drift inshore, they of course frequently make places inaccessible to fish.

Grasses and rushes and other plants, having straight stocks and no slightly submerged leaves, furnish no protection. Areas overgrown with such plants have been carefully examined for mosquito larvæ, but wherever *Gambusia* was present no immature mosquitoes were found.

The aquatic plant, *Naias flexilis*, which was common in several ponds, forming a dense growth over the bottom, normally does not provide protection, as it does not reach the surface of the water. During the severe fall drought the water, however, became so low that it was near the surface or partly exposed in many places, making such a dense mass that fish could not penetrate it. Wherever this occurred it furnished excellent protection and *Anopheles* larvæ and pupæ were common.

The duck weed, *Spirodela polyrrhiza*, was present in only one pond, over which it formed an almost continuous cover. No mosquito larvæ were seen in this pond, indicating that this plant does not furnish protection for the mosquito from fish. It, in fact, is likely that mosquitoes can not breed under such conditions, but as this pond was well supplied with *Gambusia* no data supporting this probability were obtainable therefrom.

The smart weed (*Polygonum*) is another plant that not only does not appear to provide protection but which may actually be repellent. Many places overgrown with this weed were repeatedly examined, but mosquito larvæ were not found even in apparently favorable hiding places.

Nearly all marginal plants, by projecting partly into the water, by falling into it after maturing, or by becoming partly submerged after

freshets, furnish protection for mosquito larvæ. These plants should be removed when possible.

It is evident from the study of plants in relation to mosquito control by means of fish that it is highly desirable to remove from the ponds those plants having leaves just below the surface of the water and to treat algæ in such a way as to make them useless as protectors of mosquitoes. The presence of these plants was by far the most important obstacle to be overcome in securing mosquito control in the many ponds in the extra-cantonment zone of Camp Hancock. A rather constant vigilance was necessary in order to keep a large series of ponds free of such plants, but it is not very difficult work or usually very expensive, for two laborers provided with hoes, rakes, a knapsack spray can, and some oil could take care of quite a number of ponds during the course of a season. In badly infested ponds it is occasionally advantageous to cut the vegetation with a patented device known on the market as a submarine saw.

It is very interesting to observe how quickly the top minnows learn to follow the workmen engaged in cutting and raking vegetation from ponds. They soon become quite tame and schools of them work almost under the tools of the laborers, catching mosquito larvæ and other insects as quickly as their hiding places are destroyed.

This work around the ponds caused the top minnows to become tame and that made it possible to perform certain feeding experiments which otherwise could not have been made. One of these feeding observations is described in the writer's field notes as follows: "I took several large *Anopheles* larvæ from dense vegetation and placed them in open water among top minnows. With one larva was a small piece of bark. The larva hovered over this piece of bark and the fish did not detect it. When it was placed in open water, without the least protection, the fish swam around it, even 'nosed' it, while the larva lay perfectly motionless. At last a rather small minnow seized and swallowed it. Placed another larva in open water among fish. This one too lay perfectly still, drifting like a small stick, while fish swam all about, nosing it a time or two, but apparently not detecting that it was alive and something to eat. Finally it drifted near a tuft of grass and with a surprisingly quick movement it swam into the vegetation. It was removed and placed in open water. There it lay motionless for about five minutes, when at last it was snapped up by an undersized minnow. A third was placed in open water; it too drifted along perfectly motionless for about five minutes before it was finally detected by an undersized minnow. Once this larva drifted very close to the grass from which it was originally removed, but it made no effort to get back into it. This may have been due to the presence of fish between it and the grass." In some of the feeding experiments the larvæ were much

more quickly detected by the fish than in the one just described. The rapidity with which they are found and eaten probably depends to a certain extent, at least, upon the eagerness with which food is being sought by the fish.

These feeding experiments, which were repeated many times, demonstrated that the protective instinct in mosquito larvæ is highly developed. It was shown many times that the only protection an *Anopheles* larva has from fish in open water is inactivity. When the larva thus drifts along fish evidently mistake it for an inanimate object, for, as already shown, they may swim all around it for several minutes, even touch the larva with the snout and yet not discover that it is food. The slightest movement, however, on the part of the wriggler apparently never goes unseen and it is instantly seized and devoured by the fish. It often happens that a mosquito larva placed in open water drifts toward places of protection before it is discovered by the minnows and, if no fish are very near, or are present between the larva and the place of protection, it moves toward it with a remarkable rate of speed and quickly places itself over the object near the surface of the water where it can not be seen by fish. It, however, remains motionless if fish are near.

It is not to be assumed from what has been said in the foregoing paragraphs that mosquito larvæ are as abundant in vegetation and débris when *Gambusia* is present as when absent. An *Anopheles* larva may find temporary protection over a blade of grass, but it is scarcely probable that this larva will spend its entire existence over a single blade of grass, and, if it moves, it is in great danger of losing its life. Then when it reaches the pupal stage the blade of grass is obviously not as well suited as previously to furnish protection. In this stage of life the mosquito appears to be much more active than in the larval stage. This would endanger its life still further, for it has been shown that in the presence of fish, action is certain destruction. The presence of larvæ in a pond, therefore, must not be taken as a certain criterion that fish are failing to provide mosquito control. On the other hand the many dipping experiments have shown that comparatively few mosquito larvæ are present in the best hiding places, if *Gambusia* is at hand, for rarely more than three or four larvæ were taken at one time. When *Gambusia* was absent, it, however, was not unusual to take so many larvæ at one dip that they could not be accurately counted in the dipper.

It, then, is evident that mosquito breeding, if not entirely eliminated, is at least greatly reduced by the top minnow.

VII. The Number of Top Minnows Necessary in Order to Secure Mosquito Control.

The writer has already been asked several times the general question, "How many top minnows are necessary in a pond in order to prevent mosquito breeding?" Data upon which a definite answer

could be based are extremely difficult to obtain, for there are scarcely two ponds which offer identical conditions. The size of the pond of course must be considered; whether or not it is subject to wave action is of importance; the presence or absence of vegetation is very important; and the presence or absence of enemies of *Gambusia* must not be overlooked. Even then, we can only make a guess, for anopheline mosquito larvæ, at least, breed much more prolifically in some ponds than they do in others for reasons not understood.

A pond on the Milledgeville Road belonging to the Sanitary Dairy Co. furnishes a notable example of a place which is apparently well adapted to mosquito breeding, yet during many inspections comparatively few larvæ were found. Among them were present not more than a half dozen *Anopheles*. There is much vegetation present along the shores, consisting principally of aquatic grass, and there is considerable débris. *Gambusia* is wanting and the species of fishes which are present failed to provide mosquito control elsewhere. Furthermore, wherever apparently similar conditions prevail in other ponds, particularly with respect to the presence of aquatic grass, some *Anopheles* larvæ were present regardless of the abundance of *Gambusia*.

That *Anopheles* do not breed in some places which apparently offer excellent conditions for the support of the larvæ has been noted by Le Prince and Orenstein:[1] "In many places apparently well fitted for the support of *Anopheles* larvæ they were absent yet lived and developed when placed therein as an experiment. The reason why *Anopheles* eggs are not laid in certain areas apparently in every way similar to those in which larvæ are found is yet unexplained."

It has been demonstrated through laboratory tests that one top minnow may destroy a large number of mosquito larvæ in a short time. The writer[2] observed that one adult female ate 165 large larvæ in less than 12 hours, and Seale,[3] working with this fish in the Philippine Islands, reports that one pair of half-grown *Gambusia* ate 5,041 mosquito larvæ, by actual count, from December 9, 1915, to February 25, 1916. It has been shown in this paper that a small number of minnows freed badly infested pools of mosquito larvæ in a short time; also that they destroyed the mosquito larvæ in ponds and kept the ponds free of the aquatic stages of the mosquito, unless protection was provided by plants or débris. From the knowledge which has thus been gained we may conclude that, if a pond furnishes little or no protection for mosquito larvæ, a small number of top minnows are sufficient, but if it does furnish protection a much larger

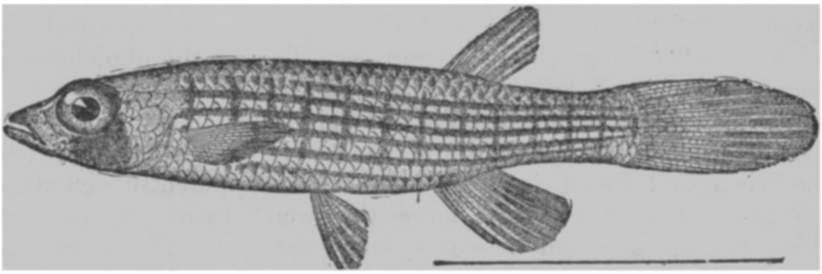
[1]Le Prince, Joseph A., and Orenstein, A. J., Mosquito Control in Panama, p. 12. Putnam, New York and London, 1916.
[2]Hildebrand, Samuel F., Report U. S. Commissioner of Fisheries, Appendix VI, 1917, p. 5.
[3]Seale, Alvin, The Philippine Journal of Science, Vol. XII, sec. D, No. 3, Manila, 1917, p. 180.

number is desirable. Antimosquito work, however, may be started with a very small number of *Gambusia*, for this fish multiplies rapidly. There appears to be no danger of overstocking, as observations indicate that the more fish a pond supports the more certain are the practical results.

VIII. Other Species of Fishes in Relation to Antimosquito Work.

No special experiments were conducted with other species of fishes in relation to mosquito control, but some information was gained from incidental observations.

The "Star headed minnow," *Fundulus nottii* (Agassiz), is probably of considerable value in antimalarial work. Its habits are very similar to those of *Gambusia*, for it feeds at the surface and frequents localities suitable for the support of mosquito larvæ. Its habits certainly are such that it is worthy of a trial. This fish occurred in a few ponds in the protected area, but as *Gambusia* was also



Fundulus nottii.

present, nothing definite in regard to their value could be learned from these sources. This species, however, was very abundant and *Gambusia* scarce in a lake located just off the Old Savannah Road, about 8 miles distant from Augusta, belonging to the Carmichael Hunting Club. This lake apparently offered excellent conditions for the support of *Anopheles* larvæ, but during two visits when several hundred yards of shore edge margined with considerable vegetation were examined only a very few larvæ were seen. The scarcity of mosquito larvæ was very probably due to the presence of *F. nottii*, unless this pond should happen to be one of those in which mosquitoes do not oviposit for reasons unknown.

Several species of sunfishes have been mentioned by authors in connection with antimosquito work, but the writer's observations indicate that they are of doubtful value. For example, one large pond supplied with bream, warmouth, and the blue spotted sunfish supported large numbers of mosquito larvæ of both types, and top minnows had to be introduced in order to secure mosquito control.

A similar condition in the presence of sunfishes, the pumpkin seed being the most abundant one, was observed by the writer on the Potomac River at Bryants Point, Md., in 1912.

The size and habitat of the pigmy sunfish suggest that it might be of value in the control of the mosquito, but the information obtained points to the contrary, for *Culex* larvæ were plentiful in unprotected places in a certain swamp where this fish was quite common.

The roach minnow, in confinement, at least, appears to destroy mosquito larvæ, as indicated in the following observation. Two minnows were left in a "bait well" when it was abandoned by bait collectors. This well was about 10 feet long and 5 feet wide with a depth of about 2 feet. The two minnows kept this well wholly free of mosquito larvæ for several months. Then an oil distributor came by, seeing that it was a favorable place for breeding mosquitoes, and not knowing of the presence of the fish, sprayed the well with oil. The oil killed the roach minnows and after it evaporated mosquito larvæ appeared in countless numbers.

Goldfish, while probably of very little value in large bodies of water where other food is obtainable, are useful in confinement. A considerable number of fountains stocked with goldfish were examined, and if they were properly built so that all parts were accessible to fish, and if fairly free of vegetation and débris, no mosquito larvæ were present.

IX. Conclusions.

1. *Gambusia affinis* is especially suitable for antimosquito work because: (*a*) It seeks its food at the surface; (*b*) it is very prolific; (*c*) it gives birth to well-developed young, therefore requiring no special environment for depositing and hatching the eggs; (*d*) It lives and thrives under a large variety of conditions and frequents areas especially suitable for the support of mosquito larvæ; (*e*) it usually lives and multiplies in ponds stocked with predacious fishes, providing it has very shallow water for refuge.

2. Plants which have slightly submerged leaves and stems or which form floating masses are the chief sources of protection for mosquito larvæ against the top minnow. Such plants should be removed from the water or treated in such a way as to make them uninhabitable for the immature mosquito.

3. Mosquitoes may breed in water so badly polluted that *Gambusia* is almost instantly killed thereby.

4. *Gambusia affinis* is of great value in antimosquito work. It eliminates the wriggler completely from ponds which are fairly free of protective vegetation and débris. If much protection is furnished by vegetation and débris, the immature mosquito is not entirely eliminated, but the number reaching the adult stage is greatly reduced.

5. The number of top minnows necessary in a body of water in order to secure mosquito control depends largely upon the conditions which prevail with respect to places of protection, i. e., a much smaller number of *Gambusia* is necessary, if the water is fairly free of hiding places for mosquito larvæ against fish, than if the reverse is true.

ANTENATAL AND NEONATAL FACTORS IN INFANT MORTALITY.

An extraordinarily helpful analysis of some of the causes of infant mortality is presented by Ballantyne in an article entitled "Antenatal and neonatal factors in infantile mortality," published in Maternal and Child Welfare, October, 1918. Inasmuch as a correct understanding of these factors underlies all effective preventive measures undertaken by health officers to lower the infantile death rate, we reproduce here the following abstract of this valuable analysis:

The author points out that at the very center of the problem of the reduction of infantile mortality lie the evaluation and analysis of the causal factors which are responsible for that loss of young lives which is still, notwithstanding all that has been accomplished in prevention and treatment, only to be fitly characterized as appalling.

On account of the defects in statistics it is not possible to know what is the total loss of young life which occurs before birth, at birth, and during the first year after birth. Some babies die in the first year of life from postnatal causes, such as the various zymotic maladies, improper feeding, defective housing, etc. Others die because of antenatal conditions, such as prematurity of birth, congenital malformations, debility, etc. Not a few die from both antenatal and postnatal causes. It is in the first month of life that these two factors tend to unite in their attack upon the newborn infant. It is at this age, after birth, that the antenatal factor is acting most powerfully, and it is at this time also, that the postnatal factor has a character which differs so markedly from that which it possesses later. Somewhere between one-third and one-half of all the deaths which occur in the first year of life take place in the first four weeks of it. Obviously, the neonatal period is a most critical one. If deaths were evenly distributed over the first year of life, one-thirteenth of them should occur in these first four weeks; but instead of that, never less than one-third of them occur then. If the fatalities of the first 4 weeks were to be continued during the remaining 48 weeks, the infantile mortality rate for the first year of life would be over 500 per thousand live births instead of 100, which it is at the present time. On the other hand, if the deaths in the first 4 weeks were to be reduced to the same proportion as those during the subsequent 48 weeks the